Computational fluid dynamics (CFD) simulation is an effective approach to develop and optimise gas drainage design for underground longwall coal mining. As part of the project supported by the Australian Government Coal Mining Abatement Technology Support Package (CMATSP), three-dimensional CFD simulations were conducted to test and optimise a conceptual design which proposes using horizontal boreholes to replace vertical boreholes at an underground coal mine in Australia. Drainage performance between a vertical borehole and a horizontal borehole was first carried out to compare their capacity and effectiveness. Then a series of cases with different horizontal borehole designs were simulated to optimise borehole configuration parameters such as location, diameter, and number of boreholes. The study shows that the horizontal borehole is able to create low pressure sinks that protect the workings from goaf gas ingresses by changing goaf gas flow directions, and that it has the advantage to continuously maintain such low pressure sinks near the tailgate as the longwall advances. An example of optimising horizontal borehole locations in the longwall lateral direction is also given in this paper.

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2. CFD model development and calibration

2.1. Site conditions and CFD model geometry

The longwall panel for this CFD study is LW3 at the Blakefield South mine located 15 km southwest of Singleton in New South Wales, Australia. The working seam was the Blakefield seam with cutting height between 2.8 and 3.4 m. LW3 was 3475 m long and 410 m wide. To mimic the situation of a fully developed goaf while saving computation time, a length of 1000 m of the goaf is selected for the CFD base model. The height of the model is 130 m, including 30 m of floor containing Glen Munro and the Blakefield seams, and 100 m of roof containing the Wambo and Redbank Creek seams and the overlying Whybrow goaf which was formed by previous mining activities. The 1000 m long model is equivalent to the goaf length of LW3 when the longwall face retreated to chainage 2475 m on 2nd October 2014, and the 5 boreholes, D, S, E, T, and U were working. Dimensions of ventilation tunnels for both main gate (MG) and tail gate (TG) side of the longwall are taken as 3 m high and 5 m wide. The face is 3 m high and 6 m wide. The geometry model of the CFD is shown in Fig. 1.

The mine employed a forcing/exhaust ventilation system consisting of two shafts, with one shaft forcing air down and the other exhausting air up from underground. On the main gate side of the LW3, there are two intakes including MG A and MG B, while the MG C is a return for the adjacent next panel. On the tail gate side, the TG A is an intake and the TG B is the return for the LW3. The air flowrate measured at TG B was 120 m$^3$/s, and the air flow rate flowing through the face was 60 m$^3$/s.

A series of site characterisation studies, field investigations, and numerical modelling studies were previously conducted to investigate longwall induced stress, fracture, permeability conditions and sources of gas emissions at the Blakefield South Mine. These results were used to construct a permeability model of the overlying and underlying strata of the mined coal seam areas for the CFD model.

2.2. Boundary conditions

During mining of LW3, the ventilation air flow rates in roadways were measured monthly as they were quite steady from time to time. And the drainage pressures, flow rate and methane concentration of the five operating vertical boreholes when the longwall face retreated 1000 m was used to calibrate the CFD model. The air flow rate flowing through the face was 60 m$^3$/s.

A series of site characterisation studies, field investigations, and numerical modelling studies were previously conducted to investigate longwall induced stress, fracture, permeability conditions and sources of gas emissions at the Blakefield South Mine. These results were used to construct a permeability model of the overlying and underlying strata of the mined coal seam areas for the CFD model.

The ventilation air flow rate, the flow rates and methane concentrations of the five operating vertical boreholes when the longwall face retreated 1000 m was used to calibrate the CFD base model in this study. Fig. 2 compares the CFD modelled ventilation and drainage data with actual field measurements at various locations of the longwall panel. It is seen that the CFD model results match well with the actual data. This demonstrates that the CFD models are able to predict realistic results for the LW3 mining conditions and the permeability model applied is reasonable and reliable for the LW3 conditions.

2.3. Gas emission sources

Gas emission sources were determined from site gas content measurements, gas composition analysis, tracer tests and monitored coal seam pore pressure change. The sources included Whybrow goaf, Redbank Creek seam, Wambo seam, Glen Munro seam and the active goaf. Gas emission rate from each source was estimated based on gas composition analysis, release percentage of gas content estimated from the empirical Flugge model, and the average thickness of each coal seam. Gas composition was set at 95% of CH$_4$ and 5% of CO$_2$ in all coal seams, and 59% of CH$_4$, 5% of CO$_2$ and 36% of N$_2$ in the Whybrow goaf, according to the gas composition analyses undertaken at the site. The gas emissions from the various sources are determined as Table 2 for the base model.

2.4. Model calibration

The ventilation air flow rate, the flow rates and methane concentrations of the five operating vertical boreholes when the longwall face retreated 1000 m was used to calibrate the CFD base model in this study. Fig. 2 compares the CFD modelled ventilation and drainage data with actual field measurements at various locations of the longwall panel. It is seen that the CFD model results match well with the actual data. This demonstrates that the CFD models are able to predict realistic results for the LW3 mining conditions and the permeability model applied is reasonable and reliable for the LW3 conditions.

3. Gas drainage comparison of vertical and horizontal boreholes

Two series of case studies were conducted. In these studies, gas emissions used in the previous calibration model were adjusted. In particular, gas emissions from Whybrow goaf used in the previous calibration model was not included, as it was assessed that gases in the Whybrow goaf did not contribute to the ventilation gas emissions in the cases of horizontal borehole drainage according to the results of a tracer test conducted at the mine. The total gas emissions of 3630 L/s of CH$_4$ and 191 L/s of CO$_2$ were used in the
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